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1981 ANNUAL PROGRESS REPORT
REVEGETATION STUDIES ON DISTURBED OVERBURDEN
ALTON COAL FIELD

by

Robert B. Ferguson

Range Scientist

In Compliance with Interagency

Agreements Ut-910-1A9-0436

and Utah-6

USDI, BLM, and USDA, USFS COOPERATING

Intermountain Forest and Range Experiment Station
Shrub Sciences Laboratory
Provo, Utah

December 30, 1981

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FOREST SERVICE REVEGETATION STUDIES AT THE ALTON COAL FIELD, UTAH

Eight studies at the Alton coal field which began in 1976, or soon thereafter, are being monitored to determine which species of shrubs, grasses, and forbs prove superior on different types of soil, over a period of years. These studies have been enumerated and described in detail in previous reports, and this report will present 1981 data according to previous study number. In each case, sufficient background material is presented to preserve continuity without referring to previous reports, except for plot diagrams. In some cases, prior years' data are presented, in addition to 1981 data, to show changes with time.

In addition to the eight studies mentioned above and the microclimate study (No. 9), three new studies were begun in 1980, to satisfy the requirements of the cooperative agreement. These new studies are also covered in this report.

Study No. 1 (Revegetation Techniques on Disturbed Overburden from Simulated Mining)

Objectives: (1) To evaluate three different soil surface cultural treatments following severe site disturbance termed "simulated mining"; (2) To compare effects of simulated mining and no simulated mining on plant establishment and growth.

Methods

An 8-acre (3.2 ha) site (464 x 800 feet or 139 x 249 m) covered by an old-growth juniper-pinyon stand was cleared and fenced to exclude deer and rabbits. Simulated mining involved stockpiling topsoil, ripping the subsoil to a depth of 30 inches (76 cm), smoothing the furrows with a dozer blade, and replacing the topsoil. Treatments are listed below, according to the same number shown on plot diagrams in earlier reports:

0. Topsoil left in place, gouged (two 32-foot-wide strips where topsoil had been piled).

1. Topsoil removed, subsoil ripped, topsoil replaced, gouged.

2. Topsoil left in place, gouged (two areas of about 1/2 acre, each, on opposite ends of the site).

3. Same as No. 1, but contour furrowed and not gouged.

4. Same as No. 1, but grass hay soil amendment spread at 2-1/2 tons per acre. Rotovated, not gouged.

A seed mixture of species shown in Table 1 was broadcast over all four treatments using hand-operated cyclone seeders, in December 1976.

Table 1. Seed mixture used on larger study areas at Alton coal field

Species	Lbs/acre	Kg/ha
Intermediate wheatgrass*	4	4.50
Pubescent wheatgrass	4	4.50
Fairway wheatgrass	4	4.50
Russian Wildrye	4	4.50
Nomad alfalfa	1	1.10
Yellowblossom sweetclover	1	1.10
Bitterbrush	2	2.25
Fourwing saltbush	2	2.25
Winterfat	0.5	0.55
Green ephedra	1	1.10
Cliffrose	1	1.10
Total	24.5	27.45

* Scientific names, common names, and species symbols are shown in the Appendix.

Results

The severe drought during the sutumn of 1976 and first 4-1/2 months of 1977 precluded normal early spring germination and emergence of seeds sown in December 1976. However, fair to good germination and emergence occurred on all treatments following a rainy period in the latter half of May 1977 (2.34 inches at Alton).

The most striking difference among these treatments, the first year, was higher frequency and numbers of grass seedlings on the area where hay was rotovated into the soil surface. At the end of the 1977 growing season, presence of grass seedlings on square-foot (0.09 m^2) plots showed 92 percent frequency on the area treated with grass hay compared to 52 percent frequency on the areas not treated with hay. Frequency of forbs was 40 percent and 21 percent on hay and non-hay areas, respectively. Comparable shrub frequencies were 4 percent and 2-1/2 percent. The most prominent shrubs were fourwing saltbush, winterfat, and bitterbrush, in that order. Mean maximum numbers of grass seedlings per square foot (0.09 m^2) was 12.8 for hay-amended plots compared to 5.2 on plots not amended with hay.

All surface cultural treatments were effective in limiting runoff from high-intensity summer storms, in 1977. Some sediment was deposited in the bottoms of terraces and pits, but the result was not serious. Minor repairs were made where a few small channels developed, mainly in wheel tracks left by equipment. No such storms occurred on this site in 1978.

Above-average precipitation during the winter of 1977-78 produced excellent growth of vegetation in the spring of 1978. Smooth brome was a prominent component of grasses where hay was used, indicating that seed of this species was present in the hay used as an organic amendment.

Table 2 shows frequency of grasses, legumes, and shrubs by treatment for the years 1977 through 1981. Overall plant frequency does not include the smooth brome component in treatment No. 4, except for the year 1977. A noticeable increase in frequency of grasses occurred in all treatments from 1977 to 1980. In 1981, the data indicated that frequency on the hay-amended area was similar to that on the ripped and gouged area (treatment No. 1).

Despite an apparent decrease in grass frequency on areas of treatments 0 and 4, good vegetative cover exists on nearly all of the study area.

The frequency values shown for legumes, in 1977, included both alfalfa and yellow sweetclover. Data shown for 1978 through 1981 include only alfalfa. Sweetclover presently is a very minor component of the vegetative stand.

Table 2. Frequency (percent) and yield (lbs/acre, airdry) of plants according to treatment and year (Alton).

Treatment	Year	Grass		Legumes		Shrubs	
		Freq.	Yield	Freq.	Yield	Freq.	Yield
0 = No simulated mining, gouged	1981	53	475	14	347	2	14
	1980	63	1664	12	897	1	--
	1979	60	1400[1]	16	490	2	--
	1978	57	--	14	--	4	--
	1977	43	--	21	--	2	--
1 = Simulated mining, gouged	1981	78	508	13	271	3	23
	1980	75	1123	15	535	1	--
	1979	71	1325	16	430	3	--
	1978	67	--	19	--	4	--
	1977	52	--	21	--	3	--
2 = No simulated mining, gouged	1981	73	580	6	127	2	12
	1980	73	828	4	195	3	--
	1979	70	895	10	105	4	--
	1978	61	--	13	--	5	--
	1977	40	--	17	--	1	--
3 = Simulated mining, contour	1981	62	583	22	498	2	4
	1980	53	903	17	765	2	--
	1979	58	1675	16	765	3	--
	1978	64	--	22	--	9	--
	1977	53	--	22	--	8	--
4 = Simulated mining, grass hay amendment	1981	78	345[2]	11	118	<1	4
	1980	89	877	21	630	1	--
	1979	87	1350	14	170	1	--
	1978	76	--	19	--	5	--
	1977	92	--	40	--	4	--

[1] Dry weight for 1979 was estimated to be 50 percent of green weight.

[2] With smooth brome added, yield for this treatment would be 537 lbs/acre in 1981, 1353 lbs/acre in 1980, and 1950 lbs/acre in 1979.

Table 2. Frequency (percent) and yield (lbs/acre, airdry) of plants according to treatment and year (Alton).

Treatment	Year	Cocklebur Freq.	Cocklebur Yield	Lespedeza Freq.	Lespedeza Yield	Smartweed Freq.	Smartweed Yield
0 = No simulated mining, ponded	1981	53	475	14	347	2	14
	1980	63	1604	12	307	1	--
	1979	60	1100*	16	490	2	--
	1978	57	--	14	--	4	--
	1977	43	--	21	--	3	--
1 = Simulated mining, ponded	1981	74	108	13	171	1	23
	1980	79	1123	15	535	1	--
	1979	71	1125	16	430	1	--
	1978	67	--	10	--	1	--
	1977	32	--	21	--	3	--
2 = No simulated mining, ponded	1981	73	580	6	127	2	12
	1980	73	839	4	105	3	--
	1979	70	805	10	105	4	--
	1978	64	--	22	--	0	--
	1977	52	--	22	--	8	--
3 = Simulated mining, grass bay	1981	82	285	22	486	2	4
	1980	53	900	17	765	3	--
	1979	34	1475	10	765	3	--
	1978	64	--	22	--	0	--
	1977	52	--	22	--	8	--
4 = Simulated mining, grass bay amendment	1981	78	345*	11	118	2	4
	1980	89	877	21	430	1	--
	1979	87	1350	14	170	1	--
	1978	78	--	19	--	5	--
	1977	82	--	10	--	4	--

* Dry weight for 1979 was estimated to be 30 percent of green weight.

2 With smooth brome added, yield for this treatment would be 537 lbs/acre in 1981, 1853 lbs/acre in 1980, and 1850 lbs/acre in 1979.

Fourwing saltbush was the most prominent shrub species in 1977, followed by winterfat. Frequency of shrubs has decreased on much of the area, indicating the severity of competition provided by the grasses. Some good fourwing saltbush plants can be found, but winterfat exhibits poor vigor wherever competition from grass is severe. Bitterbrush plants that survived are slowly becoming more conspicuous. However, if such a stand of vegetation were open to deer use, the scattered bitterbrush would be browsed back and contribute very little forage.

In Table 2, the yields shown for treatment No. 4 do not include the smooth brome component. In 1981, smooth brome produced 36 percent of the total yield of treatment No. 4.

Total yield was considerably less in 1981 than in the previous 2 years. Although yield of a newly established grass stand can be expected to decrease after the third or fourth year, much of the decrease in productivity in 1981 can probably be attributed to the low over-wintersoil moisture storage.

Study No. 2 (Effects of Organic Amendments on Growth of Selected Grasses)

Objectives: (1) To determine to what extent organic soil amendments (grass hay and bark-woodfiber compost) can improve grass growth and production on subsoil and replaced topsoil. (2) To compare response of six introduced grasses with four native grasses on different soils and amendments.

Methods

This study, established on a part of the 8-acre (3.24 ha) Alton site, involved testing the effects of all combinations of two soil types and three organic amendments on growth of 10 selected grasses. Soil types included: (1) topsoil replaced over subsoil after simulated mining, and (2) subsoil only. Soil amendments included: (1) grass hay spread at 2-1/2 tons per acre (0.9 metric tons/ha) and rotovated into the soil; (2) bark-woodfiber compost spread 1 inch (2.5 cm) deep and rotovated into the soil; and (3) no amendment. Seeds of 10 selected grasses were planted in small subplots on each of the six larger main plots in a randomized block design having three replications.

Results

Seed germination and emergence of grass seedlings did not occur until late May 1977. Cursory observations in mid-June, while seedlings were still small and not fully established, showed more seedlings present where organic amendments had been used. At the end of the first growing season (1977), grass seedlings were most numerous on the grass hay amendment plots, and fewest on the bark-woodfiber compost plots. First-year survival of streambank (Agri) and fairway (Agcr) wheatgrasses was superior among the 10 species, whereas western wheatgrass (Agsm) and Great Basin wildrye (Elci) showed fewest plant numbers. Differences among the other six grasses were less important. These six species, in descending order of maximum plant numbers, were Russian wildrye (Elju), intermediate wheatgrass (Agin[2]), smooth brome (Brin), tall wheatgrass (Agel), beardless bluebunch wheatgrass (Agin), and pubescent wheatgrass (Agtr[2]).

In the second growing season (1978), many smooth brome plants were observed on plots where the grass hay was used as an amendment. Obviously, seeds were present in the hay which added to the total amount of seed disturbed.

Crested wheatgrass and streambank wheatgrass showed highest frequency through 1979. By 1980, smooth brome had moved ahead of streambank wheatgrass, and by 1981 had taken over first place in terms of plant frequency (Table 3).

Table 3. Mean frequency (percent) of 10 grass species on small plots. Alton 8-acre study area.

Year	Brin	Agri	Agin[2]	Agtr[2]	Agcr	Elju	Agel	Agsm	Agin	Elci
1980	84	80	77	74	84	74	71	54	67	25
1981	94	78	78	76	72	68	66	59	57	36

Overall plant frequency is still higher on topsoil plots (75 percent) than on subsoil plots (62 percent) after 5 years.

The increase in plant frequency of rhizomatous species such as smooth brome and western wheatgrass was anticpiated, whereas several bunchgrass species show a decrease in frequency.

As mentioned in past reports, the addition of a hay amendment would not be recommended wherever topsoil can be replaced over subsoil materials. When topsoil is not available, it is likely that use of a hay amendment (preferably alfalfa) would improve seedling establishment.

Estimated yields continue to be significantly greater from topsoil plots (481 lbs/acre) than from subsoil plots (237 lbs/acre), but yields were not significantly different on the six soil type-amendment treatments (Table 4).

Table 4. Mean estimated yield (lbs/acre, air-dry) of grasses, according to soil type and soil amendment combinations. Alton 8-acre site.

Year	Topsoil-control	Topsoil-compost	Topsoil-hay	Subsoil-compost	Subsoil-control	Subsoil-hay
1980	854	904	799	415	407	315
1981	531	510	402	247	238	226

Among the 10 grasses tested, highest yields in 1981 were obtained from Great Basin wildrye and tall wheatgrass (Table 5). Great Basin wildrye exhibits a high yield because of very large individual plants, a characteristic of this species. Streambank wheatgrass, Russian wildrye, and western wheatgrass were the lowest-yielding species in 1981, as they were in 1980

Table 5. Mean estimated yields (lbs/acre, air-dry) of 10 grass species. Alton 8-acre study area.

Year	Elci	Agel	Agtr[2]	Agcr	Agin[2]	Agin	Brin	Agri	Elju	Agsm
1980	588	727	624	882	791	641	698	541	444	243
1981	918	640	359	357	298	276	264	209	172	122

Study No. 3 (Adaptability of Selected Grasses and Shrubs on Different Profile Materials)

Objectives: To determine the effectiveness of different grass and shrub species in forming suitable cover on different subsoil materials as well as on topsoil.

Methods

The study was established on four different types of overburden above the coal seam on a 3-acre (1.2 ha) site having a 20 to 25 percent slope and a westerly exposure. Juniper and pinyon trees were bulldozed from the areas above and below the cut area where the coal seam was exposed. The high sidewall was reduced by developing two terraces each about 25 feet (7.5 m) wide and 220 feet (67 m) long in the cut area. A 4- to 5-foot- (1.2 to 1.5 m) deep layer of dark, carbonaceous shale that lay just above the coal seam was exposed on the surface on both terraces. Three additional strips, each 50 x 220 feet (15 x 66 m), two above and one below the terraces, were prepared with different types of overburden on the surface. Starting at the top of the hill, the sequence of the four treatments was as follows:

(1) A 50- x 220-foot (15.2 x 67 m) strip of topsoil was left in place but ripped with dozer teeth to prevent runoff.

(2) A 50- x 220-foot (15.2 x 67 m) plot was stripped of approximately 1 foot (30 cm) of topsoil and 2 feet (61 cm) of gravelly clay subsoil leaving a light-colored, clay-shale surface exposed. This plot was also ripped to a depth of about 2 feet (61 cm) and furrows were left to prevent runoff and erosion.

(3) Two 25-foot- (7.6 m) wide terraces were formed where dark carbonaceous shale was exposed on the surface.

(4) A 50-foot- (15.2 m) wide strip of "fill" material consisting of the gravelly clay subsoil from (2) above.

On each of these four soil types, 12 grass species were seeded in separate plots, 10 feet wide and 50 feet long (3 m x 15 m), in two replications, except that Agcr (r) and Agsp x Agre were seeded in plots 25 feet long due to shortages of seed.

Results

The drought during the autumn and winter of 1976-1977 prevented early spring germination of seed, but good seedling emergence occurred in late May 1977. By the end of the first growing season, survival of the seeded grasses could be considered only fair to good. Ranking of the above four treatments, in descending order of plant establishment and growth, was: 1, 4, 3, 2. All grass species exhibited fair to good growth, but some were superior to others.

In 1980, mean estimated yields were significantly higher on topsoil and gravelly clay subsoil than on dark shale and blue clay soils. The same was true in 1981, a year in which the gravelly clay subsoil apparently produced as much or more forage than did the topsoil plots (Table 6). Yields on the gravelly clay subsoil may be high on this site because these plots occupy the lower area of the treated 25 percent slope, and soil moisture should be better than further up on the slope.

Table 6. Mean yields of grasses (lbs/acre, air-dry) according to four soil types. Alton 3-acre site.

Year	Gravelly clay (4)	Topsoil (1)	Dark shale (3)	Blue clay (2)
1980	660	677	356	134
1981	719	570	247	163

As suggested in our 1980 report, Great Basin wildrye increased in yield considerably in 1981 (Table 7), moving into first place among the 12 species. All the five other leading producers of 1980 showed decreases in yield in 1981. Species showing increases included the bluebunch wheatgrass-quackgrass hybrid, Russian wildrye, and beardless bluebunch wheatgrass. After 5 years, introduced species continue to produce a greater amount of forage than most native species, with the exception of Great Basin wildrye.

Table 7. Mean estimated yields (lbs/acre, air-dry) of 12 grass species, across all soil types. Alton 3-acre site.

Year	Elci	Agel	Agin[2]	Brin	Agsp x Agre	Agcr	Agri	Agin	Agtr[2]	Agcr(r)	Elju	Agsm
1980	618	1071	704	697	248	402	338	279	380	337	204	203
1981	1047	722	402	397	390	351	343	332	323	309	265	212

In 1981, "bunchgrasses" showed little change in percent frequency, ranging from a five percent increase for Russian wildrye to a six percent decrease for Great Basin wildrye. "Sod forming grasses," led by western wheatgrass, nearly all showed an increase in percent frequency (Table 8).

Table 8. Mean frequenty (percent) of 12 grass species, across four soil types on the Alton 3-acre site.

Year	Brin	Agsm	Agin[2]	Agtr[2]	Agri	Agcr	Agel	Agre x Agre	Elju	Agin	Agcr(r)	Elci
1980	73	63	66	64	58	54	58	40	44	43	43	34
1981	85	82	80	70	68	58	56	49	49	42	36	28

Culms were an average of 4 inches taller on plants growing on gravelly clay subsoil than on plants growing on topsoil. This reflects the differences in yield shown in Table 6. Culm heights were more variable on the other two soil types.

Study No. 4 (Establishment and Longevity of Several Plant Species on Various Topsoils and Shaley Overburden)

This study was officially concluded with the data taken in the 1980 field season. We did, however, obtain some additional data in 1981 that will aid us in preparing a research paper on the study.

The following is taken from the Final Report prepared for Utah International, Inc., the cooperator on the study:

CONCLUSIONS AND RECOMMENDATIONS

This study was concerned with evaluating the suitability of a carbonaceous shale overburden for use as a growing medium in future revegetation programs. We also desired to compare plant establishment and growth on layered growing media (wherein three different types of topsoil were spread over the carbonaceous shale) with that on carbonaceous shale alone. Based on 4 years of study, we draw the following conclusions:

1. The type of carbonaceous shale used in this study was not inimical to plant establishment and growth.

2. Establishment and growth of grass species would be enhanced significantly on a growing medium of carbonaceous shale by the addition of nitrogen fertilizer to the growing medium.

3. A growing medium of carbonaceous shale overlain by 10 inches of either sandy loam topsoil or loam topsoil should produce better growth of grasses than a medium of carbonaceous shale alone or of carbonaceous shale overlain by 10 inches of silty clay topsoil.

From the above conclusions, and other research summarized in this report, we recommend the following:

1. Physical and chemical properties of other strata of carbonaceous shale overburden should be analyzed to determine whether they differ significantly from those of the carbonaceous shale used in this study.

2. If carbonaceous shale overburden of the type evaluated in this study is used as a surface soil material for the establishment of vegetation, it should be fertilized in accordance with the recommendations of a competent agronomist.

3. The use of either a sandy loam topsoil or loam topsoil, as the surface 8 to 12 inches of growing medium over a deeper layer of carbonaceous shale overburden would provide a better growing medium than would the use of carbonaceous shale alone. Infiltration of precipitation would be improved, and soil moisture availability to plants would be increased.

4. A mixture of introduced and native plant species should be used when establishing vegetation by direct seeding. Based on this study, such a mixture could include: fairway crested wheatgrass, tall wheatgrass, Russian wildrye, western wheatgrass, Indian ricegrass, "Drylander" alfalfa (or other adapted species), small burnet, and fourwing saltbush. In addition, a number of other plant species can be used, based on the results of research on nearby EMRIA study areas.

Study No. 5 (A Bioassay Greenhouse Study of Different Soils from the Alton Coal Field)

Objectives: (1) To compare different soil profile materials as growing media for plants in the greenhouse, (2) To determine effects of fertilizer amendments on plant growth.

Results

This study was terminated in 1980. The reader is referred to the 1980 Annual Report for a brief summary of the results.

Study No. 6 (Growth and Development of Selected Container-Grown Shrubs and Forbs on a Drill Pad at Alton)

Objectives: (1) To compare rates of growth and development of a fairly large number of shrub species, over time, in order to select those best suited to the area, (2) to select combinations of species that would create habitat and diversity for wildlife and birds in addition to forage for livestock.

Methods

A drill-pad area on the lower edge of the 8-acre site was smoothed with a dozer blade in the fall of 1976, in preparation for planting containerized shrubs. In mid-June 1977, 25 species of shrubs plus three species of forbs were planted on an area 75 feet wide by 144 feet long. Ten plants of each species were planted in subplots 6 feet by 15 feet in size, on a 3-foot-grid spacing. The 28 species plots were replicated four times in the greenhouse. Some were 1 year old, and some were only 2-1/2 months old when transplanted in the field.

Results

Data on shrub and forb survival and growth were taken on October 1977, 4 months after planting. Survival of 22 of the 28 species was 90 percent, or more. Of the remaining six species, survival was 70 percent or more for all except bush cinquefoil, all plants of which appeared dead. Most vigorous in appearance were fourwing saltbush, wedgeleaf ceanothus, winterfat, rubber rabbitbrush, cliffrose, prostrate summer cypress, and Woods rose.

Survival data were taken again on May 11, 1978, and dead plants were replaced by live plants of the same species (where available) on May 17, 1978. Some plants of bush cinquefoil which appeared dead in October 1977 were found to be alive in May 1978. Six species requiring no replacements included black sagebrush, rubber rabbitbrush, green ephedra, golden currant, Russian olive, and scarlet globemallow. Six species needing only one plant replaced were: big sagebrush, Fremont barberry, Arizona cypress, Utah sweetvetch, cliffrose, and prostrate summer cypress. All other species required four or more replacements. Plants of fourwing saltbush appeared to have very low vigor on May 11, 1978, but recovered vigor during the summer and appeared thrifty in late September 1978. However, nearly all plants were dead in the spring of 1979. Apparently, this particular ecotype lacks sufficient coldhardiness to survive on this site.

In addition to fourwing saltbush, roundleaf buffaloberry, winterfat, and Arizona cypress each showed a loss of three or more plants per plot over the 1978-1979 winter; which was generally colder than average.

Species showing the best height growth in 1979 included Siberian peashrub, rabbitbrush, Russian olive, black shokebherry, blue elderberry, and Woods rose--all of which averaged 7 or more inches in height growth. In addition, two forbs (Utah sweetvetch and scarlet globemallow) showed excellent growth and were proving well-adapted on this site.

By the end of the fourth growing season since planting, a small amount of mortality had occurred among 14 of the 30 plant species on the site. All remaining fourwing saltbush had died during the winter of 1979-1980. Species that appeared least adapted to the climate and soils of the test site, on the basis of survival, included big milkvetch, roundleaf buffaloberry, tatarian honeysuckle, squawapple, winterfat, leadplant, and Arizona cypress. However, several excellent individual plants of buffaloberry, squawapple, and Arizona cypress were present. In fact, the mean annual height growth of Arizona cypress was exceeded by only two species: chokecherry and Russian olive. Other than the seven species mentioned above, most species were growing well. The wild rose had borne seed for two seasons and was spreading vegetatively. Golden currant and blueberry elder also produced fruit in 1980. These plots should be monitored over several more years to determine the relative merits of each species on this site.

Tables 9 and 10 show mean survival and mean plant size, respectively, at the end of each of the first five growing seasons. Very few plants died between September 1980 and September 1981. However, two of the three forb species (globemallow and big vetch appeared to be in very poor condition this year.

Greatest increases in height occurred in Arizona cypress (11 in.), golden currant (9 in.), Russian olive (6.8 in.), cliffrose (5.5 in.), Siberian peashrub (4.7 in.), and curlleaf mountain mahogany (4 in.).

A dozen species increased 4 or more inches in average diameter since September 1980. Chief among these were Russian olive, rubber rabbitbrush, rose, golden currant, big sagebrush, and Arizona cypress.

The growing season of 1981 included at least two late frosts; one in May, and one in June. On May 7, a minimum temperature of -6°C resulted in dieback of succulent growth of several species. Among the hardest hit were blueberry elder (some of which lost all new growth), Siberian peashrub, Fremont hollygrape, skunkbush, rose, globemallow, and big vetch. Tatarian honeysuckle and Arizona cypress suffered very minor damage. On June 15, a minimum temperature of -2.8°C was recorded at a height of 12 inches above ground. This may also have resulted in some damage to new plant growth at or below this height.

Table 9. Shrub survival (mean number live plants per plot: 10 possible) over five growing seasons, on the Alton drill pad site.

Symbol	Date 10/18/77	5/78 (No. replaced)	9/19/78	9/19/79	9/23/80	9/22/81
Amca	--	40	7.5	7.0	6.0	6.2
Amor	7.8	9	10.0	9.8	8.0	8.0
Arno	10.0	0	10.0	9.5	9.5	9.0
Artr	9.2	1	9.5	9.2	8.8	8.5
Agsl*	8.2	0	5.8	5.5	2.8	--
Atca	9.8	0	9.8	.5	.0	9.5[1]
Befr	10.0	2	10.0	9.8	9.2	9.0
Caar	7.2	0	7.5	7.3	7.0	7.2
Cecu	9.0	4	10.0	10.0	9.8	9.8
Cela	9.2	4	9.8	6.0	5.8	5.5
Cele	9.2	3	9.2	9.0	9.0	9.0
Cemo	9.2	5	9.8	9.5	9.5	9.5
Chna	9.8	0	9.5	9.5	9.5	9.2
Cost	9.2	3	9.8	9.0	9.0	9.0
Cuar	9.8	1	10.0	7.0	6.0	5.8
Elan	10.0	0	9.5	9.2	9.2	9.2
Epvi	10.0	0	9.8	10.0	10.0	10.0
Hebo*	9.8	1	9.2	9.2	9.0	9.0
Kopr	9.5	1	9.8	9.8	9.8	9.2
Lota	9.8	0	9.0	9.0	9.0	9.0
Pofr	10.0	1	3.0	3.0	6.0	5.5
Prvi	8.0	10	9.8	9.8	9.8	9.8
Putr	8.5	6	9.5	9.5	9.5	9.5
Rhtr	10.0	4	10.0	9.8	9.8	9.8
Riau	9.0	0	10.0	9.5	9.8	9.5
Rowo	9.2	4	10.0	10.0	10.0	10.0
Sace	10.0	0	7.8	7.8	7.8	7.5
Shro	9.5	9	9.0	2.0	1.8	1.5
Spgr*	10.0	0	10.0	9.5	7.8	5.2
Pera	--	40	4.5	5.5	5.2	5.2
Means	9.3		9.0	8.1	7.8	7.8

* = Forbs

1 = A new accession of Atca was planted in May 1981.

Table 9. Shrub survival (mean number live plants per plot; 10 possible) over five growing seasons, on the Alton drill pad site.

Species	Date				
	10/18/77	9/18/78	9/19/79	9/17/80	9/17/81
			(No replacement)		
Abca	--	10	7.5	7.0	6.0
Aber	7.8	9	10.0	9.8	8.0
Atpo	10.0	0	10.0	9.3	9.3
Artr	9.2	1	9.5	9.2	8.4
Aspl*	8.2	0	5.8	5.3	1.8
Atca	9.2	0	9.8	.2	.0
Defe	10.0	2	10.0	9.8	9.2
Chte	7.2	0	7.2	7.3	7.0
Cest	9.0	4	10.0	10.0	9.8
Cola	9.2	4	9.4	6.0	5.8
Cole	9.2	1	9.2	9.0	9.0
Cemo	9.2	3	9.8	9.2	9.2
Cuna	9.8	0	9.5	9.5	9.2
Dest	9.2	1	9.8	9.0	9.0
Duor	9.4	1	10.0	7.0	6.0
Elca	10.0	0	9.2	9.2	9.2
Fafe	10.0	1	10.0	3.0	3.0
Fred	8.0	10	9.8	9.8	9.8
Fact	8.2	4	9.2	9.2	9.2
Mace	10.0	6	10.0	9.8	9.8
Rhca	9.0	0	10.0	9.2	9.2
Rhpo	9.2	4	10.0	10.0	10.0
Saca	10.0	0	7.8	7.8	7.2
Shpe	9.2	3	9.0	2.0	1.8
Sopra	10.0	0	10.0	9.2	7.8
Vera	--	40	6.2	5.2	5.2
Mean	9.2	9.0	8.1	7.8	7.8

A = Acaca

1 = A new accession of Atca was planted in May 1981.

Table 10. Mean height and crown diameter of shrubs at the end of each year, on the Alton drill pad site.

Symbol	Height					Crown diameter			
	10/77	9/78	9/79	9/80	9/81	9/78	9/79	9/80	9/81
	- - - - - - - - - Inches - - - - - - - - -					- - - - - Inches - - - - -			
Amca	--	11.9	8.3	8.8	9.0	3.5	6.3	7.5	12.2
Amor	3.8	7.6	11.8	16.0	19.8	6.0	12.5	16.2	19.2
Arno	2.5	6.3	11.3	16.0	14.5	6.5	12.3	16.8	17.2
Artr	7.0	13.0	15.8	18.2	21.0	12.3	19.8	22.2	28.8
Asgl*	4.5	5.3	11.2	9.5	--	10.8	18.3	7.8	--
Atca	15.5	12.0	7.0	--	3.8[1]	11.4	4.0	--	4.0[1]
Befr	2.8	7.8	9.3	10.8	14.0	5.0	8.0	9.2	13.0
Caar	4.0	8.3	15.8	21.5	26.2	7.6	14.8	19.5	23.8
Cecu	9.8	10.3	14.0	17.8	19.0	13.0	17.0	21.8	28.2
Cela	9.0	9.4	15.5	13.2	13.8	8.0	13.5	11.5	13.2
Cele	4.5	8.0	10.0	15.0	19.0	6.9	13.0	15.2	18.2
Cemo	5.0	7.3	12.8	16.5	19.2	7.5	13.3	15.5	18.0
Chna	11.3	14.0	21.0	22.5	26.2	17.3	23.0	25.5	33.8
Cost	8.3	10.8	16.3	18.5	24.0	12.6	18.0	21.8	25.5
Cuar	6.5	13.5	16.8	26.0	37.0	9.5	10.8	16.0	22.5
Elan	12.8	17.8	25.5	34.2	41.0	14.8	25.8	30.2	42.5
Epvi	8.3	10.8	12.3	14.5	14.0	7.9	10.8	12.2	14.0
Hebo*	5.4	6.3	14.8	17.5	17.2	10.8	20.8	20.5	20.5
Kopr	17.0	21.0	21.8	24.0	10.0[2]	21.0	24.8	23.2	18.0
Lota	14.3	9.5	12.0	16.8	18.8	5.4	9.8	14.5	17.0
Pofr	.0	3.3	10.0	12.5	11.0	4.5	10.0	12.0	14.5
Prvi	4.8	11.9	21.0	26.5	28.5	7.4	13.5	17.8	18.2
Putr	6.3	7.8	13.3	17.0	18.8	13.3	17.5	22.0	27.5
Rhtr	10.0	10.0	15.8	19.2	21.5	12.0	21.3	23.2	27.5
Riau	6.8	17.3	18.5	23.0	32.0	15.5	19.3	25.0	31.8
Rowo	9.5	12.3	21.3	25.5	27.8	11.9	22.3	25.2	32.5
Sace	6.0	11.5	18.0	21.5	16.5	16.0	20.5	20.0	16.2
Shro	8.3	6.0	9.0	10.5	13.0	5.0	9.5	10.5	12.0
Spgr*	10.0	11.0	17.0	18.2	--	20.5	20.5	18.8	--
Pera	--	4.3	8.8	12.8	15.0	1.9	4.3	8.2	13.3
Mean	7.6	10.2	14.5	18.1	21.1	10.2	15.2	17.6	20.8

* = Forbs
-- = No data
[1] A new accession of Atca planted in May 1981.
[2] Does not include seed stalk height, as in past years.

A tent caterpillar infestation in early May resulted in severe defoliation of a number of chokecherry plants and lesser amounts of defoliation of several rose, bitterbrush, and curlleaf mountain mahogany plants. Granular diazinone was sprinkled on the "tents" on May 12, and all plants had recovered by the end of the growing season.

Although 1981 was not a good seed year, the following species produced some seed: leadplant, big sagebrush, Siberian peashrub, winterfat, rubber rabbitbrush, tatarian honeysuckle, shrubby cinquefoil, and rose.

At the beginning of this study, it was realized that most of these shrub species could not be expected to attain their maximum growth rates of the test plot because of the close spacing between individuals. We considered thinning the plants, but decided against it. The most vigorous individual of each species will probably become dominant. In addition, by allowing the severe competition to continue, we should learn more about which species are the toughest competitors in the test environment.

Study No. 7 (Compatability of Selected Container-Grown Shrubs with Various Grasses on Four Soil Types)

Objectives: (1) To compare growth rates of 10 selected shrubs in competition with each of 11 selected grasses on different soils.

Methods

In early May 1978, container-grown plants of the following 10 shrub species were planted on one replication described in Study No. 3: fourwing saltbush, Bonneville saltbush, winterfat, curlleaf mountain mahogany, true mountain mahogany, green ephedra, prostrate summer cypress (two varieties), skunkbush sumac, and bitterbrush.

A single row of each shrub species was planted across all 11 grass plots on each of the four types of soil. Shrubs were planted approximately 5 feet (1.5 M) apart, so that in any single row, two plants occurred in each 10-foot-wide (3 M) grass plot, making a total of 22 plants per row. Rows were also spaced approximately 5 feet (1.5 M) apart, so that all 10 shrub species occurred on each of the four types of soil.

Results

All shrub species showed excellent survival at the end of the first growing season and differential survival by the end of the fourth growing season (Table 11). Greatest decline in numbers of plants between 1978 and 1981 occurred on topsoil plots. Apparently, the heavier grass cover on topsoil plots offers more competition to shrubs than they encounter on other types of soil materials where grass is less productive. It should be pointed out that one of the main reasons for the decrease in plant numbers on dark shale is the fact that the upper terrace has sloughed off, and many plants close to the edge were destroyed or covered up. Species most affected by sloughing were prostrate summer cypress, curlleaf mountain mahogany, and winterfat. Shrub species showing best overall survival in competition with grasses were fourwing saltbush, villous prostrate summer cypress, and skunkbush.

From the standpoint of size, superior shrub species are bitterbrush, fourwing saltbush, and villous prostrate summer cypress (Table 11). When Table is compared with Table 6, it is quite apparent that shrubs are better adapted on sterile soil material such as the blue clay and dark shale than are the grasses. Grasses will require nitrogen fertilization on sterile soil materials for best productivity. In this study, fertilizer was not added to the different types of soils.

The competitive effect of the various grass species on overall shrub survival and growth is shown in Table 12. After five growing seasons, shrub survival was highest on plots of western wheatgrass, Russian wildrye, Great Basin wildrye, and beardless bluebunch wheatgrass. All except Russian wildrye are native grasses of the Intermountain area. Lowest overall survival occurred on plots of the bluebunch wheatgrass x quackgrass hybrid, intermediate wheatgrass, and pubescent wheatgrass. Western wheatgrass, prostrate summer cypress, and alfalfa appeared to be most palatable to rabbits that have occasionally found their way into the study area.

Table 11. Number of plants, mean height, and mean crown diameter of 10 shrub species growing on four different soil types at Alton. Data taken in September 1978, 1979, 1980, and 1981*.

		Topsoil			Blue clay			Dark shale			Gravelly subsoil			Means		
Symbol	Year	No. plants	Ht. In.	Crown dia. In.	No. plants	Ht. In.	Crown dia. In.	No. plants	Ht. In.	Crown dia. In.	No. plants	Ht. In.	Crown dia. In.	No. plants	Ht. In.	Crown dia. In.
Cemo	1978	21	9.4	2.3	22	10.0	3.0	20	7.1	3.0	22	6.9	2.7	21.2	8.4	2.8
	1979	16	9.9	4.0	21	8.8	5.2	17	8.5	5.8	19	7.7	5.1	18.2	8.7	5.0
	1980	11	6.6	2.9	21	9.2	7.2	17	10.5	7.9	17	8.1	6.4	16.5	8.6	6.1
	1981	9	7.6	5.9	21	11.7	10.8	17	17.1	13.2	17	8.6	8.8	16.0	11.2	9.7
Putr	1978	12	8.2	3.9	19	6.7	4.0	21	7.1	4.1	21	7.0	6.6	18.2	7.3	4.6
	1979	13	9.1	7.4	16	11.8	12.1	15	12.1	13.5	21	13.8	15.0	16.2	11.7	12.0
	1980	11	12.2	12.4	17	13.3	18.1	17	15.9	18.5	21	19.8	20.9	16.5	15.3	17.5
	1981	12	14.7	17.2	17	20.9	31.7	17	23.6	31.5	21	22.5	26.9	16.8	20.4	26.8
Rhtr	1978	21	9.5	3.1	22	9.1	3.4	22	6.9	3.1	22	7.9	3.3	21.8	8.4	3.2
	1979	20	6.8	4.5	20	10.9	7.4	22	8.3	7.1	22	8.5	6.6	21.0	8.6	6.4
	1980	17	7.9	5.1	20	11.6	11.0	22	9.1	8.4	19	8.5	6.3	19.5	9.3	6.4
	1981	17	9.0	7.7	21	13.3	16.4	22	10.5	12.0	19	9.1	9.6	19.8	10.5	11.4
Epvi	1978	22	7.1	3.8	22	6.9	4.1	22	6.7	3.4	22	6.9	3.7	22.0	6.9	3.8
	1979	15	8.3	4.4	21	11.1	6.4	18	5.5	3.4	20	7.8	4.5	18.5	8.2	4.7
	1980	9	10.5	4.4	21	10.7	7.3	18	4.5	3.0	20	6.5	3.3	17.0	8.1	4.5
	1981	8	10.0	6.2	21	12.3	9.9	18	5.2	4.1	18	7.7	4.7	16.2	8.8	6.2
Cele	1978	20	6.6	2.7	20	4.8	2.1	21	4.5	2.4	22	4.5	2.5	21.8	5.1	2.4
	1979	16	9.1	5.0	19	7.6	4.4	1	10.0	9.0	22	6.9	4.9	14.5	8.4	5.8
	1980	16	9.7	6.4	20	8.5	5.7	1	17.0	14.0	22	7.0	5.1	14.8	8.5	7.8
	1981	15	11.3	9.8	19	10.4	9.9	**	**	**	21	7.8	7.9	18.3	9.8	9.2
Cela	1978	22	9.8	5.6	22	8.5	4.2	22	9.6	6.6	20	5.7	4.2	21.5	8.4	5.2
	1979	18	10.6	6.0	15	11.2	7.6	11	7.3	5.6	18	10.6	6.0	15.5	9.9	6.3
	1980	15	10.1	7.0	15	9.4	8.5	11	5.2	4.0	9	5.5	4.0	12.5	7.5	5.9
	1981	13	14.5	11.2	13	10.7	10.9	**	**	**	8	6.4	5.5	11.3	10.5	9.2
Atbo	1978	20	5.2	3.8	22	4.6	4.0	22	11.4	10.8	22	8.4	7.9	21.5	7.4	6.6
	1979	12	5.4	4.1	20	7.7	7.1	13	8.4	8.0	12	5.4	4.1	14.2	6.7	5.8
	1980	6	5.0	2.2	15	6.2	6.6	6	4.2	3.8	11	8.4	6.8	9.5	6.0	4.9
	1981	2	5.0	4.0	17	7.6	10.1	9	5.1	5.4	9	9.3	12.3	9.2	6.8	8.0

Table 11 (continued).

Kopr	1978	18	4.1	4.4	22	3.7	4.6	20	7.1	9.8	21	13.8	19.3	20.2	7.2	9.5
	1979	12	16.6	7.9	19	18.6	13.4	5	22.5	14.0	12	16.6	7.9	12.0	18.6	10.8
	1980	11	13.0	7.6	18	15.3	13.8	5	18.2	19.2	20	29.4	29.4	13.0	19.0	17.5
	1981	10	7.8	9.2	18	8.1	13.6	9	6.6	7.0	20	16.7	24.2	14.2	9.8	13.5
Atca	1978	22	7.0	5.8	22	6.5	6.6	22	15.8	16.9	22	17.8	18.0	22.0	11.8	11.8
	1979	21	10.5	6.0	22	12.0	11.5	22	13.1	15.2	19	28.2	26.7	21.0	16.0	14.8
	1980	17	9.8	5.2	20	12.5	12.5	19	13.6	13.7	21	24.3	22.5	19.2	15.1	13.5
	1981	17	10.2	6.6	21	20.7	20.9	19	19.3	19.7	22	30.5	33.9	19.8	20.2	20.3
Kovi	1978	22	10.0	7.0	22	5.5	4.9	22	7.2	7.2	22	12.3	12.0	22.0	8.8	7.8
	1979	20	21.0	12.5	22	25.3	19.2	22	26.0	17.4	20	21.0	12.5	21.0	23.3	15.4
	1980	19	16.6	10.3	21	19.7	14.0	17	25.7	19.8	19	19.0	14.0	19.0	20.3	14.5
	1981	19	9.8	11.5	22	9.2	14.5	15	10.1	19.0	18	12.3	17.4	18.5	10.4	15.6
Means	1978	20.0	7.7	4.2	21.5	6.6	4.1	21.4	8.6	6.7	21.6	9.1	8.0	21.1	8.0	5.8
	1979	16.3	10.7	6.2	19.5	12.5	9.4	13.3	11.1	9.0	18.5	12.6	9.3	16.9	11.7	8.5
	1980	13.2	10.1	6.4	18.8	11.6	10.5	13.3	12.4	11.2	17.9	13.6	11.9	15.8	11.9	10.0
	1981	12.2	10.0	8.9	19.0	12.5	14.9	15.8	12.2	14.0	17.3	11.9	15.1	16.0	11.8	13.0

* Twenty-two plants of each species were planted on each soil type.
** These species destroyed by soil sloughing of terrace wall.

Table 12. Overall survival, mean height, and mean diameter of shrubs competing with 11 different species of grass, after four growing seasons at Alton.

Grass species	Shrubs			
	No.	Survival (%)	x Ht. (in.)	x Dia. (in.)
Agcr	54	68	12.5	14.0
Agel	56	70	11.2	11.7
Agin	60	75	14.3	16.9
Agin	47	59	10.9	11.4
Agri	57	71	13.4	14.6
Agsm	64	80	12.5	13.9
Agsp x Agre	45	56	13.9	15.7
Agtr	51	64	10.9	12.3
Brin	56	70	12.6	14.5
Elci	60	75	13.7	16.7
Elju	62	78	13.0	14.1

Study No. 8 (Exploratory Study on Adaptability of Tree-Like Species)

Objectives: (1) To determine whether certain tree species will survive and grow on severely disturbed soils in this environment.

Methods

This should be regarded as a preliminary study to determine whether additional work is justified with some of the species being tested. Species in this study were grown in containers at the Couer d'Alene Nursery and the Provo greenhouse, as follows: bur oak, bigtooth maple, horse chestnut, black chokecherry, American plum, and hybrid poplar. Most plants were less than 1 foot in height.

Plants were transferred to the field from containers in the spring of 1978. The six species were planted on contour trenches that had been made in 1977 with a dozer blade on the 3-acre Alton site where the slope is 25 percent or greater. A Latin-Square design was used so that one plant of each species appeared in each row and in each column. Rows corresponded to single contour trenches. Plants were spaced approximately 8 feet apart in both directions, in adjacent Latin Squares.

Results

At the end of the first growing season, bigtooth maple exhibited the best survival percentage (92 percent), and bur oak the poorest survival (33 percent). After four growing seasons, none of the six test species have survived very well or grown well. In fact, height measurements taken in 1981 show that none of the surviving trees are as tall as they were in 1979. Most have suffered winter die-back each year.

These trees have had to compete with a good stand of grass on a west-facing slope. All normally grow in areas receiving more precipitation than the study area.

From this preliminary test, we conclude that bur oak and horse chestnut are not adapted to the environment of the Alton coal field. The other four species may be of use only on more mesic exposures or where better-than-normal soil moisture conditions could be provided.

Table 13 shows the trend in percent survival of the six tree species planted in this study.

Table 13. Percent survival of six tree species at end of the first four growing seasons.

Year	Oak	Bigtooth maple	Horse chestnut	Black chokecherry	Hybrid poplar	American plum
1978	33	92	42	50	67	42
1979	25	25	8	33	50	42
1980	0	17	0	0	25	17
1981	0	8	0	0	17	17

Table 13. Percent survival of six tree species at end of the first four growing seasons.

Year	Oak	Eastern hemlock	Norway spruce	Black cherry	Hybrid poplar	American elm
1978	33	92	42	50	67	42
1979	25	25	8	33	50	42
1980	0	17	0	0	25	17
1981	0	8	0	0	17	17

Study Nc. 9 (Microclimatological Studies)

Objectives: (1) Instrumentation has been established over several years on the three experimental sites described in this report, including the 8-acre study site, 3-acre study site, and Utah International Cooperative study site. Objectives were to monitor soil moisture, air and soil temperatures, and soil salinity of reconstructed sites over a period of time. Effort on each of the sites is discussed separately.

Utah International Study Site

Methods;

Soil moisture sensors and soil salinity sensors were installed in December 1976, at three depths at a single location within each of the 16 plots (four soils x four replications). Depths were 20, 46, and 76 cm (8, 18, and 30 in, respectively) below the soil surface. Locations were at the same point within each plot, 2.1 m (7 ft) below the upper edge and 1.5 m (5 ft) in from the sides.

Soil moisture and salinity were monitored on five occasions during the 1977 growing season. Soil moisture was monitored at weekly intervals from early May through October 30, in both 1978 and 1979, and from late May through September in 1980. Soil salinity was measured in early May from sensors, and at the end of October from soil samples, in both 1978 and 1979; and from soil samples in November 1980 and October 1981.

Results:

Measurements of soil moisture on the four different soil material profiles of the Utah International cooperative study site were discontinued at the end of the 1980 season.

A final report on this study was prepared and sent to Utah International, Inc. We expect to publish a research paper summarizing the results of this cooperative study. A discussion of the soil moisture patterns exhibited by the study plots will be included.

Eight-Acre Study Site

Methods:

On May 17, 1979, a battery powered (solar-charged) automatic data logger was installed at the 8-acre study area on the Alton coal field. This instrument monitors four sensors at hourly intervals and stores the data on magnetic tape. Measurements are taken of air temperature at 12 and 54 inches above the ground, soil temperature at a depth of 8 inches, and precipitation.

In addition, on June 1, 1979, single-junction thermocouple psychrometers were embedded in the soil of each of the six soil type/soil amendment combinations on one replication of the study plots. Three locations were selected on each soil type/soil amendment area. An effort was made to select locations where an area of at least 2 square feet of bare soil occurred. This was done to minimize the effects of plant roots on soil water content. At each selected location, psychrometers were placed at depths of 8 and 20 inches. The first measurements of soil water potential were made on June 21. Beginning on July 7, measurements were made at essentially weekly intervals through October 30, 1979. In 1980, the first measurements were made on May 1. However, problems with the microvoltmeter used to obtain readings from the thermocouple psychrometers prevented further data from being obtained until July 12. Thereafter, readings were taken at weekly intervals through September 28, 1980. In 1981, thermocouple psychrometer readings were taken at weekly intervals from May 12 through September 30.

Results:

Tables 14, 15, and 16, show the monthly mean, mean maximum, and mean minimum air and soil temperatures for the period of mid-May 1979 through June 1981. Table 17 shows monthly extreme temperatures recorded at the 8-acre study area.

The frost-free season at the 8-acre site was 156 days long in 1979, compared to a frost-free period of 124 days at Alton, and 173 days at Kanab. In 1980, the frost-free seasons at the 8-acre site, Alton, and Kanab were 141, 108, and 144 days long, respectively. The length of growing season (number of consecutive days with a minimum temperature above 0°C) may be considerably shorter for plants growing closer to the surface of the ground. Data taken at a height of 12 inches at the 8-acre study site show that the length of growing season there was only 118 days in 1979, and 113 days in 1980. In some years, and in locations where cold air accumulates ("frost pockets"), the growing season will be even shorter. Most of the Alton coal field will be in Zone 5 on the Rehder-Wyman hardiness zone scale (Zone 6a, USDA scale).

Table 18 shows the mean soil water potential, expressed in bars, at approximately 14-day intervals through the 1981 observation period, as obtained from readings of the thermocouple psychrometers.

On May 15, both the topsoil and subsoil plots that were amended with hay had higher soil water potentials at the 8-inch depth than did compost-amended soils or non-amended soils of the same type. This relationship lasted only until early June. During the remainder of the 1981 growing season, mean soil water potentials on the topsoil plots was lower on the hay-amended treatment than on either the compost-amended or the check treatment. On subsoil plots, there was little difference in soil water potentials among the three treatments.

As in 1980, soil water potentials were lower in topsoil plots than on subsoil plots throughout the growing season of 1981.

Three-Acre Study Site

Methods:

On June 1, 1979, single-junction thermocouple psychrometers were enbedded in the soil of each of the four soil types involved in this study. Three locations were selected on each soil type. As on the 8-acre area, an effort was made to select locations where an area of at least 2 square feet of bare soil occurred. This was difficult to do on the topsoil plots because of the overall high density of grass. At each selected location, psychrometers were placed at depths of 8 and 20 inches. The first measurements of soil water potential were made on June 21. Beginning on July 7, measurements were made at essentially weekly intervals until October 30, 1979. As on the 8-acre study area, first measurements of soil water potential in 1980 were made on May 1. Subsequent measurements were made at weekly intervals from July 12 through September 28, 1980. In 1981, thermocouple psychrometer readings were obtained at weekly intervals from May 12 through September 30.

Table 19 shows mean soil water potential, expressed in bars, at approximately 14-day intervals throughout the summer of 1981.

Results:

The pattern of soil water potential exhibited by the four soil materials has been quite similar during each of the three seasons (1979, 1980, and 1981). In May, the topsoil at the 8-inch depth has the highest water potential, whereas there is no difference between water potentials of the four soils at a depth of 20 inches.

Beginning in the latter part of June, and continuing throughout the remainder of the summer, the soil water potential of topsoil at the 8-inch depth becomes lower than that of the other three soil materials. Most likely, this is a reflection of the greater grass density on the topsoil plots, but differences in soil texture could also be responsible.

As in 1979 and 1980, soil water potential measurements on this study site show that plants have not been subject to any severe moisture stress, as far as the moisture tension in the soil is concerned. This is not to say that during periods of prolonged drought, or unusually high temperatures, no moisture stress will be experienced. Rather, it indicates that such conditions did not occur during the three summers of study.

Overwinter soil moisture storage was very low for the winter of 1980-1981. However, the month of March 1981 brought 220 prcent of the long-term average precipitation for March (based on records for the town of Alton). The remainder of the 1981 growing season was variable with respect to precipitation received; April was near average, May 220 percent of average, June 20 percent of average, July about 50 percent of average, and August and September just slightly above average. All things considered, soil moisture availability was adequate but not plentiful throughout most of the growing season. Table 20 shows the precipitation received at the 8-acre study area compared to that received at the town of Alton, 10 miles to the northwest.

Table 14. Monthly mean air and soil temperature (C°), May 18, 1979 through June 1981. Alton 8-acre study area

Date	Air @ 54"	Air @ 12"	Soil @ -8"
1979			
May (18-31)	14.1	13.6	14.5
June	18.4	17.6	19.0
July	22.2	21.4	22.9
August	19.4	19.0	21.8
September	18.9	18.1	20.6
October	12.5	11.5	16.1
November	1.2	.4	6.0
December	.5	- .8	2.7
1980			
January	.0	- .8	1.9
February	2.5	- .1	1.7
March	1.5	.0	1.4
April	7.9	7.7	7.6
May	10.0	9.7	11.2
June	18.4	17.2	18.5
July	21.2	20.5	21.6
August	20.1	19.7	22.2
September	17.1	16.6	18.9
October	10.0	9.2	13.0
November	4.9	3.9	6.3
December	4.2	3.3	3.9
1981			
January	2.1	1.5	3.6
February	2.5	2.0	3.8
March	2.7	2.7	5.1
April	9.5	9.2	10.0
May	12.0	11.9	14.3
June	20.8	20.7	20.8

Table 15. Monthly mean maximum air and soil temperature (C°), May 18, 1979 through June 1981. Alton 8-acre study area

Date	Air @ 54"	Air @ 12"	Soil @ -8"
1979			
May (18-31)	22.8	24.4	15.6
June	26.8	29.4	20.4
July	31.6	35.4	24.3
August	28.6	31.5	23.2
September	28.5	32.3	21.8
October	21.4	28.5	17.1
November	8.8	11.4	6.6
December	9.1	11.4	3.2
1980			
January	6.6	4.5	1.9
February	10.8	3.7	1.7
March	8.8	5.4	1.7
April	15.2	17.3	8.5
May	16.9	18.8	11.8
June	26.9	29.2	19.8
July	30.4	33.9	22.9
August	28.8	32.9	23.5
September	25.7	29.5	19.1
October	18.8	22.1	13.9
November	14.0	18.0	7.0
December	13.5	17.3	4.4
1981			
January	10.8	14.7	4.2
February	11.2	14.9	4.3
March	9.6	12.7	5.7
April	17.2	20.7	10.8
May	19.5	23.2	15.3
June	29.3	33.5	22.0

Table 16. Monthly mean minimum air and soil temperature (C°), May 18, 1979 through June 1981. Alton 8-acre study area

Date	Air @ 54"	Air @ 12"	Soil @ -8"
1979			
May (18-31)	6.5	4.7	13.5
June	9.0	6.1	17.6
July	12.4	8.9	21.5
August	11.0	7.9	20.6
September	10.2	6.2	22.5
October	4.5	.2	15.1
November	- 4.8	- 8.8	5.5
December	- 5.6	- 9.6	2.2
1980			
January	- 4.3	- 4.7	1.6
February	- 3.6	- 2.7	1.7
March	- 4.7	- 5.1	1.2
April	1.0	- 1.0	6.8
May	2.3	.8	10.4
June	8.5	4.8	17.2
July	12.2	9.6	20.4
August	11.5	7.8	21.0
September	8.8	5.2	17.8
October	2.4	- 1.1	11.6
November	- 2.3	- 6.6	5.7
December	- 2.3	- 5.6	3.6
1981			
January	- 4.4	- 8.8	3.2
February	- 4.8	- 8.1	3.4
March	- 3.0	- 5.5	4.6
April	1.7	- 1.1	9.2
May	4.4	1.7	13.5
June	11.4	7.8	19.7

Table 16. Monthly mean minimum air and soil temperature (C°), May 16, 1979 through June 1981. Alton 8-acre study area

Date	Air @ 50"	Air @ 12"	Soil @ -8"
1979			
May (16-31)	0.5	4.7	13.3
June	3.0	8.1	17.6
July	11.4	8.0	21.3
August	11.0	7.3	20.6
September	10.3	6.7	22.3
October	4.5	.7	15.1
November	- 4.8	- 3.8	5.3
December	- 3.6	- 9.0	2.2
1980			
January	- 4.3	- 4.7	1.6
February	- 3.0	- 5.7	1.7
March	- 4.7	- 5.1	1.3
April	1.0	- 1.0	6.8
May	2.3	.8	10.4
June	12.2	9.0	20.4
July	11.5	7.6	21.0
August	8.8	5.2	17.8
September	7.4	- 1.1	11.0
October	- 2.5	- 6.0	3.7
November	- 2.5	- 5.0	3.6
December			
1981			
January	- 4.4	- 5.8	3.2
February	- 6.8	- 8.1	2.4
March	- 3.0	- 5.6	4.6
April	1.7	- 1.1	8.1
May	4.4	1.7	13.5
June	11.4	7.8	19.7